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PENNSYLVANIAN STRATIGRAPHY OF NORTH CENTRAL TEXAS

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INTRODUCTION

The Pennsylvanian strata of north central Texas furnish a beautifully exposed and nearly complete section of the rocks of this period, exceedingly variable in lithologic character and prolific in well-preserved fossils. Yet because of their isolation and the semiarid, somewhat forbidding character of the country in which they outcrop, detailed study of them has been long delayed. The discovery in recent years of great deposits of petroleum within this area has brought to it many geological workers, and has served as a great stimulus to the study of the stratigraphy, differentiation, and correlation of its formations.

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[1] Published by permission of the Director, Bureau of Economic Geology and Technology, University of Texas.

Previous work.—The Pennsylvanian area of Texas was first explored by Roemer[1] in 1846 and later by Shumard,[2] Ashburner,[3] and others. The most important contributions to the stratigraphy of the north Texas country, however, are contained in the writings of Tarr,[4] Cummins,[5] and Drake,[6] who made investigations of the coal fields of the Colorado and Brazos river valleys in the late eighties and early nineties for the first Texas Geological Survey.

Cummins[7] recognized six divisions in the rocks of the Texas Pennsylvanian, (1) Bend, including the black shale and limestone typically exposed in San Saba County; (2) Millsap, comprising shale, limestone, and sandstone exposed in the Brazos River Valley; (3) Strawn, including the strata, chiefly shale and sandstone, between the first coal and the base of the massive limestones of the succeeding division; (4) Canyon, the dominantly limestone division in the middle or upper part of the Pennsylvanian section; (5) Cisco, composed of shale, sandstone, and thin limestones above the Canyon limestones and below the Red Beds; and (6) Albany, consisting of thick limestones and shales above the Cisco, at first thought to belong to the Coal Measures, but later referred to the Permian. Cummins did not attempt to subdivide these large units, but the broad groups which he recognized and the names which he applied are those in use at the present time. In the main they appear to be very well chosen and the contributions of this pioneer worker based on work done under great difficulties are most important.

Drake[8] was first to make a detailed study of any portion of the Pennsylvanian in Texas. In mapping the coal field of the Colorado River Valley, he differentiated the large groups of Cummins into many smaller units which he described and named. He fixed the limits of the Strawn, Canyon, and Cisco in the area studied by him, designating definite stratigraphic horizons at the top and bottom of each. Many of the subdivisions defined by Drake are employed in the present classification, but in a number of cases it has seemed necessary to depart from his usage and to apply appropriate geographic names for units to which he gave merely descriptive names, as "Cherty" or "Coral" limestone.

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[1] F. Roemer, *Die Kreidebildungen von Texas* (Bonn, 1852).

[2] B. F. Shumard, *Trans. St. Louis Acad. Sci.*, Vol. I (1860), pp. 686–87.

[3] C. A. Ashburner, *Trans. Amer. Inst. Min. Engrs.*, Vol. IX (1881), pp. 495–506.

[4] R. S. Tarr, *Texas Geol. Surv., First Ann. Rept.* (1889), pp. 201–16.

[5] W. F. Cummins, *Texas Geol. Surv., First Ann. Rept.* (1889), pp. 145–82; *Second Ann. Rept.* (1890), pp. 359–94.

[6] N. F. Drake, *Texas Geol. Surv., Fourth Ann. Rept.* (1892), pp. 357–481.

[7] W. F. Cummins, *Texas Geol. Surv., Second Ann. Rept.* (1890), p. 375.

[8] N. F. Drake, *loc. cit.*

In addition to the investigators whose work has just been mentioned, a considerable number of geologists have reported studies of value on various portions of the Texas Carboniferous beds. Among these may be mentioned Hill,[1] Gordon,[2] Paige,[3] Udden,[4] Girty,[5] Moore,[6] and Plummer.[7] All of these investigations have been studied carefully by the writers in connection with the present work.

Recent investigations.—In December, 1916, the geologists of the Roxana Petroleum Corporation began the systematic mapping of the surface and structural geology of the northern portion of the Pennsylvanian area in Texas. As the work progressed the maps were fitted together and the data slowly compiled for a new, detailed, geological map of north Texas. At present almost the entire area of the Pennsylvanian outcrops has been mapped, the outcrops of all the principal limestones and many other beds having been traced by means of plane table and alidade. Several hundreds of geological sections have been measured and carefully described. Fossils have been collected from most of the stratigraphic divisions, those from some horizons having been studied in detail. Finally, much information has been obtained from the records of numerous wells over a large area in north Texas which have been drilled deeply into or through the Pennsylvanian.

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[1] R. T. Hill, *U.S. Geol. Surv., Twenty-first Ann. Rept.* (1901), Part VII.

[2] C. H. Gordon, *U.S. Geol. Surv., Water Supply Paper 276* (1911).

[3] Sidney Paige, *U.S. Geol. Surv., Geol. Atlas, Folio 183* (1912).

[4] J. A. Udden, *Bur. Econ., Geol., and Tech., Bull. 44* (1916).

[5] G. H. Girty, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. III (1919), pp. 71–81.

[6] R. C. Moore, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. III (1919), pp. 216–52; G. H. Girty and R. C. Moore, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. III (1919), pp. 418–20.

[7] F. B. Plummer, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. III (1919), pp. 132–50.

Acknowledgments.—Cordial acknowledgment is made of the assistance of Dr. W. A. Van Waterschoot Van der Gracht, president of the Roxana Petroleum Corporation, and of Mr. Richard Conkling, head geologist, through whose courtesy the results of the stratigraphic studies of the Texas Pennsylvanian are presented. Among the geologists who have contributed importantly to the progress of the study are Messrs. John Burtt, Paul Applin, James Armstrong, Sam Wells, Chester Hammill, Angus McLeod, Grady Kirby, E. G. Allen, and Miss Linda Green.

GENERAL DESCRIPTION OF THE NORTH CENTRAL TEXAS PENNSYLVANIAN

Location.—The Pennsylvanian area of north central Texas may be described as two great inliers of Carboniferous rocks which protrude through the Cretaceous strata on the east and dip beneath Permian rocks on the west and north. The two areas are separated by a narrow tongue of Cretaceous (Trinity) sand, and the southern outcrop rests against Ordovician rocks for a short distance along the Llano uplift, so that the southern portion does not possess the relations of a true inlier.

The total area covered by the Pennsylvanian is about 7,000 square miles. It includes the west part of Montague, the southeast part of Clay, the greater portion of Jack, Young, Stephens, Palo Pinto, Eastland, Brown, the east half of Coleman, the north part of San Saba, and the northeast of McCulloch counties. The shape and location of the Pennsylvanian area are shown on the index map, Figure 1.

Lithologic character.—The lower portion of the Pennsylvanian rocks consists of massive blue, gray, or black limestone, and greenish-gray to black argillaceous and bituminous shale. As observed at the outcrop, these are not interbedded, but a division consisting almost wholly of limestone, 400 to 500 feet in thickness, lies between two shale formations. This portion of the Pennsylvanian, the Bend, contrasts in lithologic character with the remaining rocks of the system. It is the chief petroliferous horizon in north Texas.

The Millsap and Strawn divisions are dominantly clastic, the latter, especially, being composed of very massive, more or less conglomeratic sandstones and alternating sandy shales. The resistant beds in this portion of the section are beautifully exposed over large areas in the Colorado and Brazos river valleys.

The Canyon consists of massive limestones, from a few feet to as much as 250 feet in thickness, alternating with shales. Although commonly designated a limestone division, its character is in no way comparable to the Bend, for in the Canyon, the limestones are thinner and are interbedded with the shales. The limestones are hard, fine-grained, in part very cherty, and are not as a whole very fossiliferous. The shales are chiefly yellow to gray in color and clayey rather than sandy.

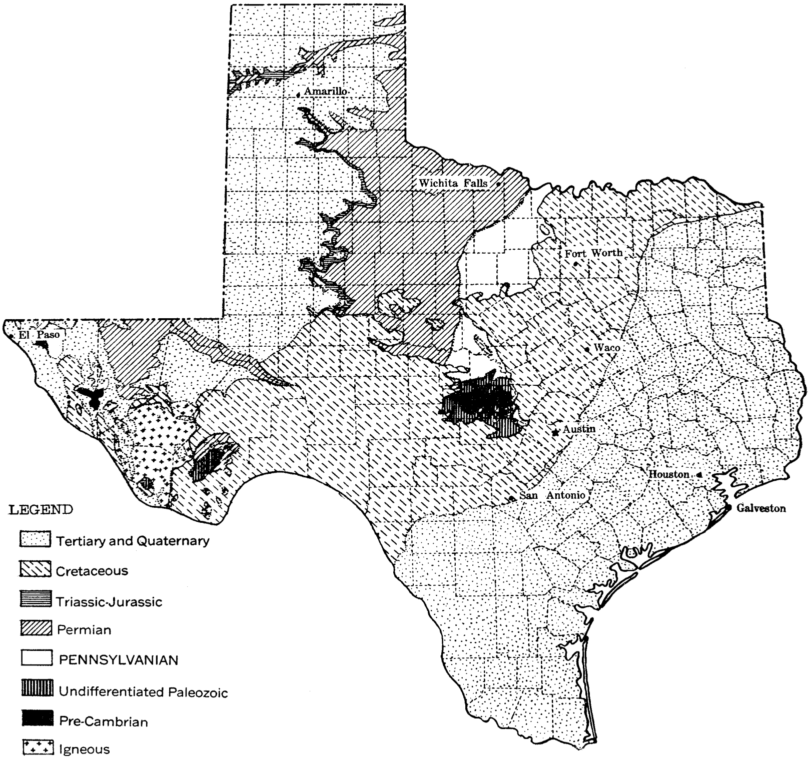

FIG. 1—Index geological map of Texas

The Cisco is composed of thick shales and more or less conglomeratic sandstones, thin limestones, and some coal. The shale and sand are much the most important rock types, but the limestones form persistent escarpments and are prominent, especially in the upper part and to the south. Conglomerates are found chiefly in the north. They are composed, for the most part, of small angular fragments of the resistant materials from other sedimentary formations. The shales are commonly sandy. The limestones are for the most part fine-grained and yellow to gray in color.

Thickness.—The total thickness of the Pennsylvanian of Texas, computed from measurements of the surface outcrops, is as a maximum about 6,800 feet. A compilation of average thicknesses for each of the divisions gives a total of 5,350 feet. As a matter of fact, the thickness of the total section is somewhat less than the total of measurements of thickness at the outcrop, for there appears to be a very important overlap of the beds from east to west, so that above the Bend the older divisions disappear successively in going to the west. This is illustrated by the diagrammatic section, Figure 2.

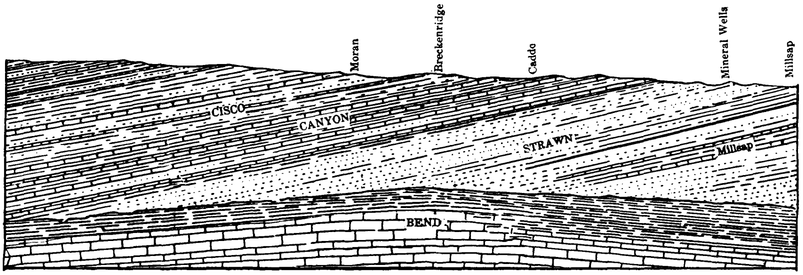

FIG. 2.—Diagrammatic section through the Pennsylvanian of Texas

The average thicknesses of the divisions of the Pennsylvanian in Texas are indicated in the table of formations.

Topography.—The outcrop of the Pennsylvanian rocks and of each of the major divisions of the Pennsylvanian in north Texas is characterized by the topography. The Pennsylvanian area as a whole is distinguished by its prominent and very persistent escarpments. Due to the character of the soil and the climate, there is a widespread cover of mesquite, scrub oak, and cactus, with belts of

CLASSIFICATION OF THE TEXAS PENNSYLVANIAN

		Thickness in Feet	Colorado River Valley	Brazos River Valley
Cisco Group	Putnam formation	125–175	Coleman Junction limestone Santa Anna Branch shale	Coleman Junction limestone Santa Anna Branch shale
	Moran formation	150–200	Sedwick limestone Santa Anna shale Horse Creek limestone = ? Watts Creek shale	Sedwick limestone Shale Dothan limestone Shale
	Pueblo formation	150–200	Camp Colorado limestone Shale Stockwether limestone = ? Camp Creek shale	Camp Colorado limestone Shale Eolian limestone Shale
	Harpersville formation	200–275	Saddle Creek limestone Shale and coal	Saddle Creek limestone Shale Belknap limestone Shale and coal Crystal Falls limestone Shale and sandstone
	Thrifty formation	100–200	Breckenridge limestone Shale "Lower Chaffin" limestone (Drake) = ? Shale "Speck Mountain" limestone (Drake) = ? Shale and sandstone	Breckenridge limestone Shale Black Ranch limestone Shale Ivan limestone Shale Avis sandstone
	Graham formation	100–600	Wayland shale Gunsight limestone Bluff Creek shale	Wayland shale Gunsight limestone South Bend shale Bunger limestone Gonzales Creek shale Jacksboro limestone Finis shale
Canyon Group	Caddo Creek formation	30–150	Home Creek limestone Hog Creek shale	Home Creek limestone Hog Creek shale
	Brad formation	175–250	Ranger limestone Placid shale Clear Creek limestone Cedarton shale	Ranger limestone Seaman Ranch shale
	Graford formation	170–450	Adams Branch limestone Brownwood shale Capps limestone bed Rochelle conglomerate	Adams Branch limestone Brownwood shale
	Palo Pinto limestone	50–100	Not present	Palo Pinto limestone

CLASSIFICATION OF THE TEXAS PENNSYLVANIAN—*Continued*

		Thickness in Feet	Colorado River Valley	Brazos River Valley
Strawn Group	Mineral Wells formation	500–800	Undifferentiated	Keechi Creek shale Turkey Creek sandstone Salesville shale Lake Pinto sandstone East Mountain shale Brazos River sandstone Mingus shale Thurber coal
	Millsap formation	1,800–3,000		Millsap formation (undifferentiated)
Bend Group	Smithwick shale	400	Undifferentiated	Present, but not exposed
	Marble Falls limestone	400–500	Undifferentiated	
	Barnett shale	0–50	Undifferentiated	

cedar locally along the prominent limestone ridges. The area of the Bend has a rough, semimountainous topography which results from the resistant character of the massive, thick limestone of the Marble Falls formation. The Strawn area is distinguished by prominent but irregular escarpments which are produced by the hard sandstone beds. The weathering of the shales and the disintegration of the sandstone produces flat, sand-covered bottom lands, but the bold escarpments along Brazos and Colorado rivers dominate as topographic features. The Canyon, as the name somewhat fortuitously suggests, gives rise to a very rough, deeply chiseled topography which is one of the prominent geographic features of north central Texas. The massive limestone beds make high, sharp-edged escarpments which make travel from east to west very difficult. The Cisco produces a topography of gentler relief, with broad, open valleys and less prominent, though well-defined, escarpments.

Divisions.—In making the new geological map of the Texas Pennsylvanian, attempt has been made to present a classification which, conforming as closely as possible to the well-known divisions of Cummins, will apply equally to the whole area from the north to the south. Carefully measured and studied sections across the

Pennsylvanian along a number of selected lines were compared, and data gathered from mapping and evidence from invertebrate fossils were considered. The resulting classification of the sediments is shown in the following table.

BEND GROUP

The strata included in the Bend group are exposed in northern San Saba, McCulloch, western Lampasas, and Burnet counties, areas bordering the Central Mineral Region of Texas. The group is named from McAnnelly's Bend in Colorado River (Fig. 3). It consists of three formations, the Barnett shale at the base, the Marble Falls limestone in the middle portion, and the Smithwick shale at the top. The total thickness in the region of outcrop is about 850 to 900 feet.

The Barnett shale, named from springs east of San Saba, is a yellowish-gray to black, bituminous shale ranging in thickness up to 50 feet, the average being about 30 feet. Its outcrop forms a narrow, smooth pathway between the rough, broken terranes of limestone on either side, the Ellenburger (Ordovician) below and the Marble Falls above. This pathway many of the roads in San Saba County follow. Though represented in numerous well records north of the outcrop, the Barnett is not found everywhere at the base of the Bend group, as at the type locality of the Marble Falls limestone on Colorado River at Marble Falls. Where the Barnett is absent the base of the succeeding limestone commonly appears to be somewhat conglomeratic, containing débris evidently derived from the subjacent Ordovician limestones. The Barnett shale is not very fossiliferous, except locally where certain marly beds contain numerous fossils. The chief distinguishing features of the fauna are the goniatites *Glyphioceras cumminsi* and *G. incisum* and the brachiopod *Liorhynchus carboniferum.* The cephalopods, which were first described by Hyatt, Smith[1] referred to the European species *Goniatites striatus* and *G. crenistria.* Girty[2] included *G. striatus* in the synonymy of *G. choctawensis*, but it appears that the Bend fossils are most probably distinct from these. *Liorhyn-*

[1] J. P. Smith, *U.S. Geol. Surv., Mon. 42* (1903), pp. 68, 80.

[2] G. H. Girty, *U.S. Geol. Surv., Bull. 439* (1911), p. 97.

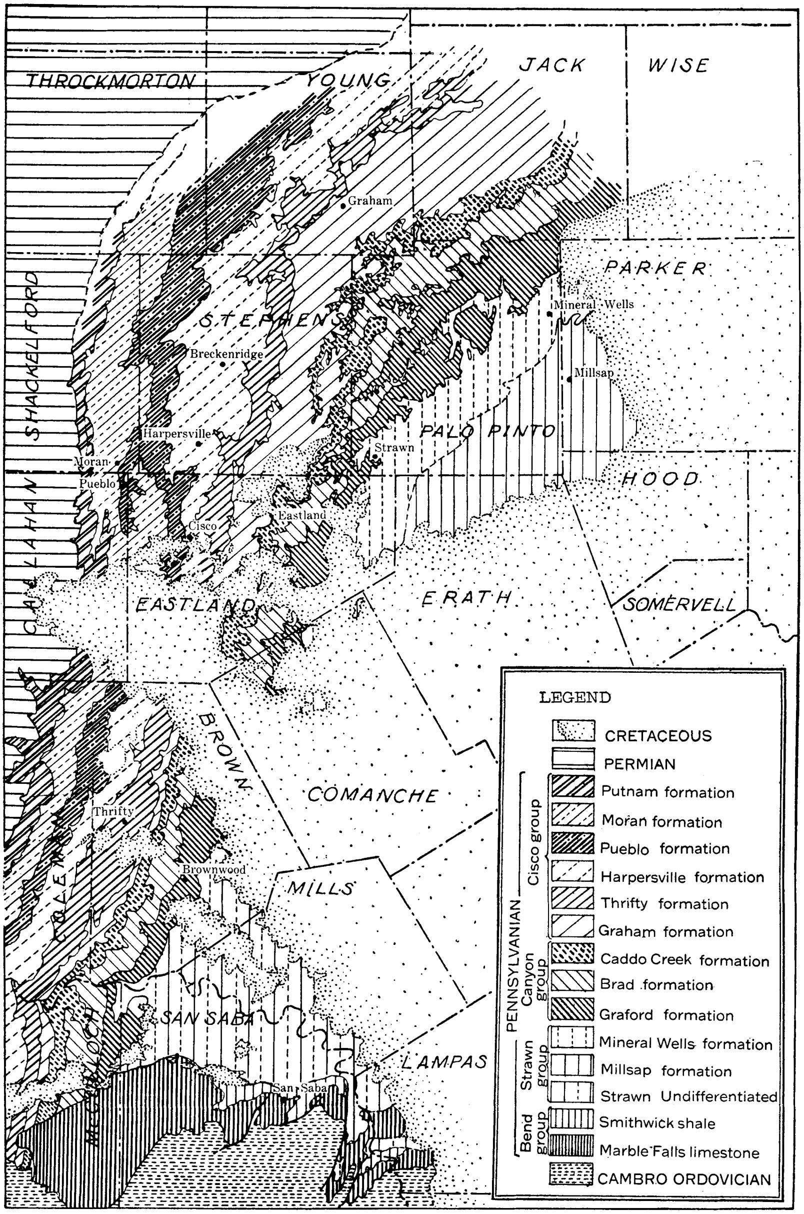

Fig. 3.—Map showing outcrops of Pennsylvanian formations in north central Texas.

chus carboniferum is reported from the Moorefield shale of northern Arkansas, in the Floyd shale of Alabama, and elsewhere in beds which are referred to the Upper Mississippian. Accordingly Girty[1] regards the Barnett as late Mississippian in age and therefore distinct from the remainder of the Bend which is undoubtedly Pennsylvanian. Goldman,[2] studying samples of cuttings from two wells north of the outcrop, believes that certain lithologic characters differentiate the lower shale, and that it is separated by a stratigraphic break from the overlying beds. Through the courtesy of the United States Geological Survey, Mr. Moore has recently had opportunity to examine particularly the contact between the Barnett and the succeeding Marble Falls divisions. It has been found that although the characteristic Barnett fauna is obtained in a limestone which apparently marks the base of the Marble Falls, there is really a sharp line of faunal demarcation between this and the Marble Falls divisions which is also distinguished by a thin zone of glauconite and phosphatic pebbles. The fauna of the Barnett is unlike that of the succeeding beds and resembles most closely that from formations which are regarded as Upper Mississippian. The Barnett shale is therefore tentatively referred to the Mississippian rather than the basal Pennsylvanian where it was placed in the previous correlation of the writers.

The Marble Falls limestone is a massive, resistant formation which is well exposed throughout the region of its outcrop. It is somewhat irregularly folded and faulted, and because of the lack of continuous exposures or readily identifiable horizons within the formation it is difficult to measure an accurate section of the unit as a whole. Its total thickness in the region of its outcrop, however, appears to be about 400 to 500 feet. In the surface exposures no sandstone and practically no shale is observed in the Marble Falls formation; but to the north well records show the occurrence of some shale interbedded with the limestone and also the presence of some limestone in the succeeding Smithwick shale. The Marble Falls limestone is but sparsely fossiliferous in some exposures, but in parts of San Saba County numerous beautifully preserved fossils have been collected. Altogether more than 150 species have been identified in studies reported by one of the writers,[1] which show that in spite of a very considerable proportion of species which have not previously been described the fauna is undoubtedly representative of the Lower Pennsylvanian. Forms which are commonly found only in Mississippian strata, as the coral *Paleacis*, occur in the Marble Falls, but the dominant element of the fauna belongs without question to typical Pennsylvanian species.

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[1] G. H. Girty, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. III (1919), p. 72.

[2] M. I. Goldman, *U.S. Geol. Surv., Prof. Paper 129-A* (1921).

The Smithwick shale is typically a fine-grained, black or olive-green, rather fissile, bituminous formation which rests conformably upon the Marble Falls limestone. It has a total thickness of about 400 feet. Excellent exposures are found along Colorado River near Smithwick, Marble Falls, and Bend, but the outcrop is in most places marked by areas of very gentle relief where the shale has been covered by débris from weathering. The drainage, as shown in the course of San Saba River, appears to have become adjusted to the surface geology, the larger streams following the outcrop of the easily eroded Smithwick shale. Fossils are few in the black, bituminous portion of the Smithwick, but in the gray portion a varied fauna has been obtained in which the mollusks are, as might be anticipated, the dominant element. The fauna is related to that of the Marble Falls formation, but contains a number of forms not found in the beds below.

The Bend group may be correlated with the Morrow group of northeastern Oklahoma and northern Arkansas and with the horizon of the Wapanucka limestone in southern Oklahoma. Not only is there a notable similarity in the faunas of these beds, but a number of species which have been reported only from them appear to be in common. However, *Pentremites* and *Archimedes*, which have been found in both the Morrow and the Wapanucka, are not known in the Bend. As has been indicated, the Pennsylvanian aspect of the fauna is evident. If the Morrow belongs to the Upper Pottsville, as indicated by plant fossils studied by White,[2] it would appear that the Bend belongs to a late portion of the Pottsville. On account of the unconformity and pronounced change in the character and the considerable thickness of the succeeding Strawn strata which appear certainly to be not younger than Allegheny, the writers are inclined to refer the Bend to a somewhat earlier position in the Pottsville, possibly as indicated by Ulrich,[1] the Lower Pottsville. It may be noted that some of the Bend fossils, as among the cephalopods *Paralegoceras iowense*, which are reported from other portions of the American Pennsylvanian, do not appear to be identified correctly with these species, and their significance in correlation is therefore not so important.

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[1] R. C. Moore, *loc. cit.*

[2] David White, *U.S. Geol. Surv., Nineteenth Ann. Rept.* (1898), Part III, p. 469; *Twentieth Ann. Rept.* (1900), Part II, p. 817.

STRAWN GROUP

The Strawn group includes all the strata between the top of the Smithwick shale and the base of the Palo Pinto limestone in the Brazos River Valley or its stratigraphic equivalent in the Colorado River Valley. The rocks of this group are distinguished chiefly by their clastic character, especially the thickness of coarse sandstones, and by their irregularity in bedding (Fig. 4). The two main areas of Strawn outcrop, one in the valley of Colorado River and the other in the valley of the Brazos, are broadly similar, but it has not been possible to identify divisions of the one in the other. In the northern area there are exposed in the upper part of the Millsap division a number of beds of limestone which are found nowhere to the south, from which it appears that the waters of the Brazos River Valley were farther from the land of Strawn time than those of the Colorado. The entire section of the Strawn is observable along Colorado River, but in the Brazos Valley a considerable thickness of beds belonging to the lower portion of the Strawn are not exposed on account of the Cretaceous overlap from the east. In both areas there is indication of a very marked overlap of the Strawn from east to west, the successively younger strata of the group extending farther to the west than the older.

The Strawn of the Colorado River Valley lies in the area studied by Drake.[2] In his work the alternating subdivisions of sandstone and shale are differentiated in some twenty units which he termed

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[1] E. O. Ulrich, *U.S. Geol. Surv., Prof. Paper 24* (1904), p. 111.

[2] N. F. Drake, *op. cit.*, pp. 375–89.

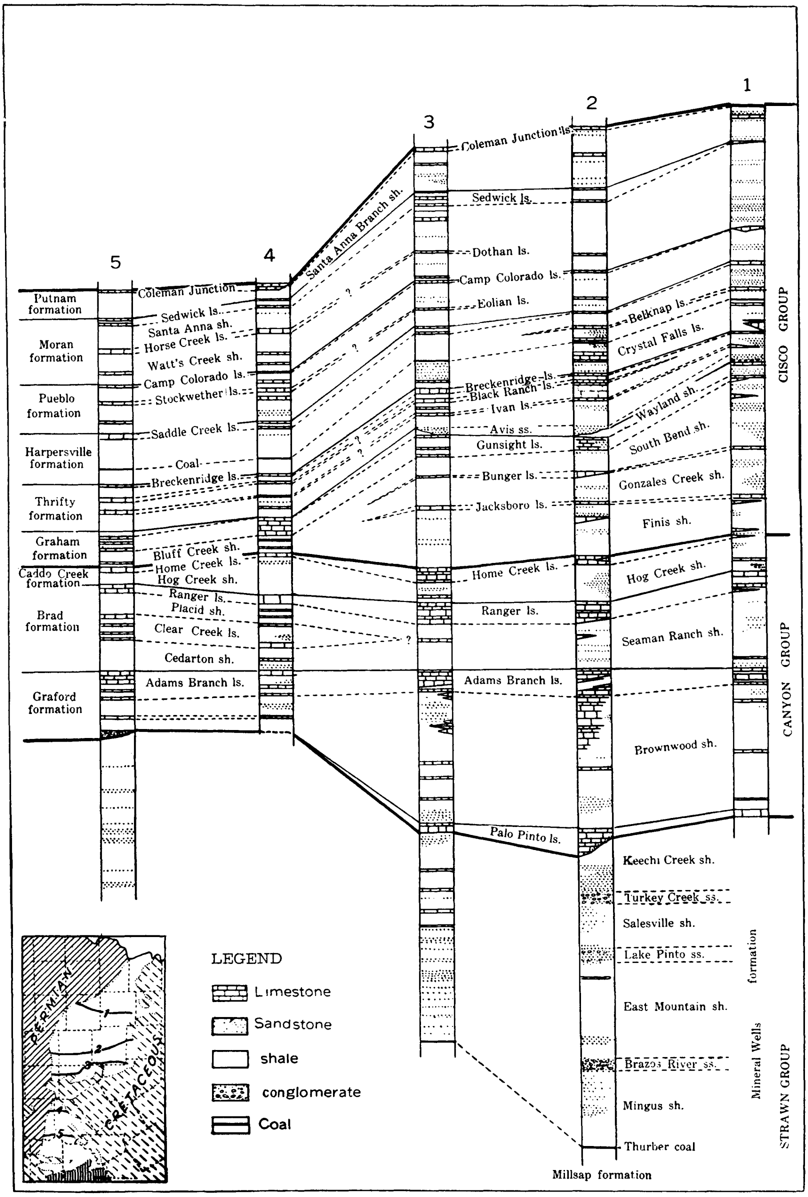

FIG. 4.—Stratigraphic sections through the Pennsylvanian of north central Texas. (1) Brownwood-Trickham section; (2) May-Coleman section; (3) Strawn-Baird section along Texas & Pacific Railway; (4) Mineral Wells-Moran section; (5) Jacksboro-Newcastle section.

beds and to which he applied stratigraphic names. The outcrops of these beds extend from south to north across the Strawn area, the dip being more or less steeply to the west. The sandstones form escarpments, but because of variations in the deposits these are very irregular and are not readily traceable or easily differentiated, as are the limestone escarpments higher in the section. The thickness of the Strawn in the Colorado River Valley as determined from measurements at the outcrop is more than 3,800 feet, but the drill shows that the greatest thickness south of Brownwood is not more than 1,200 feet. Wells 5 miles west of Brownwood show a thickness of the Strawn amounting to 700 feet, and 9 miles north of Coleman only 500 feet. Near Brady the Strawn is apparently not represented, and higher divisions of the Pennsylvanian rest directly upon the Bend.

In the Brazos River Valley two main divisions of the Strawn have been identified, the Millsap formation below and the Mineral Wells formation above. Only the upper portion of the Millsap formation is exposed at the surface, outcrops being found in the eastern part of the Strawn area near Millsap and along Brazos River in southwestern Parker County. The limestones which appear in this part of the section are quite unlike any beds observed in the Mineral Wells formation. Cummins[1] defined the Millsap division in 1890 to include all the beds in the Brazos River Valley below "coal seam No. 1" (Thurber coal) and the top of the black Smithwick shale. Thus the lower portion of the Millsap formation is known only from drill records. As a whole, the formation consists mostly of dark blue and clayey shale, limestone, and several thin, light-colored, friable sandstones. Locally it contains oil and gas in commercial quantities. Well records show its thickness in the Strawn area to range from 1,800 to 3,000 feet, and as in the case of the Strawn of the Colorado River Valley the thickness diminishes to the west: 2,200 feet at Brad in Palo Pinto County; 1,600 feet at Caddo in Stephens County; and 800 feet at Breckenridge, Stephens County.

The Mineral Wells formation includes the sandstones and shales of the upper part of the Strawn in the Brazos River Valley above the Thurber coal. It is very well exposed in the vicinity of Mineral Wells and along Brazos River, its outcrop extending in a belt 10 to 15 miles wide from Erath to Jack and Wise counties. Four prominent sandstone members produce prominent escarpments which are the chief topographic features of the region. The shales are sandy and are at least in part very fossiliferous.

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[1] W. F. Cummins, *Texas Geol. Surv., Second Ann. Rept.* (1890), p. 372.

Fossils from the Strawn collected by the writers are chiefly from the Millsap and the middle portion of the Mineral Wells formation in the Brazos Valley. The fauna of the Millsap, so far as known, is not very large, nor does it contain strongly diagnostic elements, but it appears to be more closely related to that of the Bend than the Mineral Wells. A large and varied fauna is found in the Mineral Wells formation, more than 90 per cent of which is common to the Wewoka fauna of southern Oklahoma which has been studied in detail by Girty.[1] Without doubt these faunas are very closely related, but since this fauna with some minor changes occurs in the Canyon group and in the Graham formation of the Cisco, and since in southern Oklahoma it is found as low as the Hartshorn sandstone,[2] many hundreds of feet below the Wewoka formation, it is believed that the stratigraphic equivalent of the upper Strawn in southern Oklahoma is below the horizon of the Wewoka. From evidence at hand the Strawn of Texas may be correlated with beds below the Calvin sandstone of the section northeast of the Arbuckle Mountains, with the Vinita and Winslow formations of the region farther north, and probably in part the Cherokee shale of Kansas and Missouri. It is evidently of Allegheny age.

CANYON GROUP

The Canyon group includes the beds formed after the deposition of the coarse sandstones, conglomerates, shales, and coal of Strawn time, when the land to the east had been worn low, the accumulating sediments forming a series of thick limestones and fine calcareous clays, with only a few lenses of sandstone. As here defined, the Canyon group includes the strata assigned to it by Cummins[3] in his section along Brazos River, that is, from the base of the massive limestone on the East Fork of Keechi Creek, now named the Palo Pinto limestone, to the top of the massive limestone which outcrops near Finis on the line between Jack and Young counties. The latter has been found to be equivalent to the Home Creek limestone of Drake in the Colorado River Valley. Conditions were more uniform in the north Texas region during the Canyon epoch, and it is possible to trace many of the stratigraphic subdivisions for very long distances. As shown in the table of formations, there are four formations in the Canyon of the Brazos Valley, in order from the bottom: Palo Pinto, Graford, Brad, and Caddo Creek; in the Colorado Valley there are three, the Palo Pinto not being represented. The total thickness of the group ranges from an average of about 500 feet in the south to 800 or 900 feet in the north. The outcrop is correspondingly wider in the north.

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[1] G. H. Girty, *U.S. Geol. Surv., Bull. 544* (1915).

[2] G. H. Girty, *U.S. Geol. Surv., Nineteenth Ann. Rept.* (1898), Part III, p. 541.

[3] W. F. Cummins, *Texas Geol. Surv., Second Ann. Rept.* (1890), p. 374.

The Palo Pinto limestone is a thick, crystalline, dark gray rock made up typically of beds 2 to 6 inches in thickness and having a total thickness of 50 to 100 feet. It forms a prominent escarpment across Palo Pinto County and has been traced for a long distance in the Brazos Valley. It has not, however, been identified south of the Cretaceous overlap in Eastland County which separates the Pennsylvanian outcrops. The basal beds of the Canyon consist here of wave-worked sands, thin, brecciated limestone containing pebbles of black limestone, chert, and conglomerate. Evidently there was land no great distance farther south, in the region of the present Llano Mountains. The chief distinguishing feature of the fossils which have been found in the Palo Pinto formation is their very robust size, many species being represented by individuals more than twice the normal size.

The Graford formation, named from the town of Graford in northern Palo Pinto County, consists of a thick, locally very fossiliferous shale, the Brownwood member, below, and a massive escarpment-forming limestone, the Adams Branch member, above. These divisions are well developed both in the south, where they were differentiated by Drake, and in the north. The Brownwood shale is about 160 feet thick near Brownwood, but at least 400 feet near Graford. A conglomerate at the base of the formation in the

Colorado Valley has been named the Rochelle conglomerate, and a thin lentil of limestone which is traceable for a considerable distance in the lower part of the Brownwood in Brown County is named the Capps bed. The Adams Branch limestone has a thickness of 10 to 30 feet in the southern Pennsylvanian area, but northward it increases locally to more than 100 feet. A varied fauna has been collected from the Graford formation, the most numerous fossils coming from the Brownwood member. While it contains some species, in part undescribed, not known in the Wewoka fauna, and lacks many which occur in the southern Oklahoma formation, it is a local modification of this fauna and corresponds to it more closely than to any other. A thin bed about 60 feet below the top of the Adams Branch limestone, characterized by an abundance of a very elongate, emaciated *Fusulina*, has been identified throughout the extent of this member.

The Brad formation, named from Brad in Palo Pinto County, rests conformably upon the Graford. It consists of limestone and shale, a massive, very cherty limestone, the Ranger member, marking the top. The Brad formation has been traced from near Stewarton in Jack County to Brady in McCullough County, its average thickness in the north being about 225 feet, and in the south about 200 feet. The lower part of the formation consists of shale with thin limestones and some sandstone, and in the north all the strata below the Ranger limestone are included in the Seaman Ranch member. In the Colorado River Valley, however, three members are distinguished below the Ranger: the Cedarton shale and sandstone, 20 to 80 feet at the base; the Clear Creek limestone, 10 to 25 feet, next above; and the Placid shale, 30 to 50 feet, beneath the Ranger. The Ranger limestone, which was called by Drake the "Cherty limestone," is readily distinguishable because it is the only uniformly cherty bed in the Canyon. Its thickness ranges from 10 to 50 feet.

The Caddo Creek formation, named from a tributary of the Brazos in Stephens County, has been mapped from eastern Jack County southwest and south to a point near Brady. In the north its average thickness is 100 to 150 feet, in the south 30 to 50 feet. It consists of two members, both named by Drake in the Colorado

Valley, the Hog Creek shale below, and the Home Creek limestone above. The shale is rather sandy, and especially in the north grades into a thick, cross-bedded sandstone at the top. The limestone, or rather the series of thin limestones, at the top of the Caddo Creek, has a thickness of 10 to 50 feet and in the extreme northern portion of the outcrop disappears.

A review of the paleontologic evidence and the stratigraphic relations of the Canyon group leads to the conclusion that this portion of the Texas Pennsylvanian is approximately contemporaneous with the upper portion of the section described in the Coalgate area[1] of southern Oklahoma, that is, Calvin to Holdenville, and perhaps some of the subjacent beds. This includes the Wewoka formation. Since the horizon of the Calvin has been traced northeastward to the Claremore, and this in turn to the base of the Marmaton formation in Kansas, it appears that surface-mapping checks the paleontological correlation made by Girty[2] and the Wewoka formation may be regarded as equivalent to a portion of the Marmaton. The horizon of the Lenapah limestone which belongs in the upper part of the Marmaton formation has also been traced across most of Oklahoma and appears to lie just above the Wewoka.

CISCO GROUP

The upper portion of the Texas Pennsylvanian included in the Cisco group is characterized by its more clastic sediments, its thin but persistent limestones, and the presence of coal. It includes all the beds between the Home Creek limestone of the Canyon and the lowermost beds containing Permian fossils. The change in the character of the rocks in passing from the Canyon to the Cisco is evidently the result of a diastrophic movement which made shallow the waters in northern Texas and which brought into them large amounts of coarse sand and gravel, chiefly from the north, for the northern portion of the Cisco is materially thicker and more clastic than the southern portion. The total thickness of the Cisco group is about 700 to 800 feet in the southern Pennsylvanian area and 1,400 to 1,500 feet in the north. Six formations have been recognized in the Cisco, as indicated in the foregoing table of stratigraphic divisions, in order from the base: Graham, Thrifty, Harpersville, Pueblo, Moran, and Putnam. As a whole, the Cisco group is not more fossiliferous than other parts of the Texas Pennsylvanian, but some beds, as the upper shale of the Graham formation, are among the most fossiliferous in the mid-continent region.

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[1] J. A. Taff, *U.S. Geol. Surv., Geol. Atlas, Folio 74.*

[2] G. H. Girty, *U.S. Geol. Surv., Bull. 544* (1915).

The Graham formation, named from the county seat of Young County, a place already known to science on account of the unusual ammonoids which have been collected there by J. P. Smith[1] and others, appears to rest disconformably upon the Canyon beds. The older or lower members of the Graham are present only in the north, pinching out southward and being overlapped by the younger or higher members. The formation is distinguished from the underlying beds by its very clastic character and thinner limestones, and from succeeding beds by its prolific and characteristic fauna. The subdivisions of the Brazos Valley include the Finis shale and sandstone at the base, Jacksboro limestone, Gonzales Creek shale, Bunger limestone, South Bend shale, Gunsight limestone, and Wayland shale. In the Colorado River Valley there are the Bluff Creek shale, Gunsight limestone, and Wayland shale. The limestones are in each case very thin and are not so persistent as the limestones of the Canyon. The Jacksboro and Gunsight are locally characterized by an extraordinary abundance of the coral *Campophyllum torquium.* The shales, especially the Wayland shale, contain very numerous fossils which for the most part are beautifully preserved and weather out readily from the shale. The fossiliferous zone of the Wayland has been traced in some detail from northern Jack County to Brown County, a distance of some 175 miles, and at every point where suitable exposures were found the characteristic fauna was discovered. One locality a mile south of the town of Gunsight, in southern Stephens County, contains the most surprising profusion of well-preserved fossils which has come under the observation of the writers. The fauna is very closely related to that of the Wewoka formation in Oklahoma, for not only is a very large proportion of the species common to both, but a number of rare species which may be considered as satisfactory index fossils are found in both. One very interesting element in the Graham fauna is the group of ammonoids, or, in part, true ammonites, which occurs in the Wayland shale. While a number of these have been found nowhere outside of the Graham, they are very strongly suggestive of the Permian; indeed, so much so that if the associated invertebrate fauna and stratigraphic position were less definitely certain, the containing rocks would probably be regarded as Permian. The Graham formation is referred to the Upper Coal Measures and is believed to be approximately equivalent in age to the Kansas City formation of the Kansas section. There are marked similarities in the faunas of these horizons, and each is followed by a pronounced change in fauna, marked by the disappearance of many of the common elements in the previous invertebrate groups and by the appearance of new forms such as *Enteletes hemiplicata*, *Chonetes granulifer meekianus*, and other shells, which became widely distributed and abundant in the closing portion of the Pennsylvanian. The greater thickness of the Graham formation in the north, 500 to 600 feet as compared with 100 feet or less in the south, and its much more clastic character in the north appear to be associated with the uplift of the Arbuckle Mountains in southern Oklahoma which independent studies indicate was subsequent to the time of the deposition of the Wewoka formation and long after the beginning of the Pennsylvanian.

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[1] J. P. Smith, *loc. cit.*

The Thrifty formation, named from the town in central Brown County, includes the strata from the sandstone which disconformably overlies the Graham formation to the top of the limestone which forms a prominent escarpment in the town of Breckenridge, Stephens County. The formation consists of thick shales which are less fossiliferous and brighter in color than those of the Graham, limestones which are thicker and somewhat more massive than those of other divisions of the Cisco, and some sandstone and coal. It has been mapped from Jermyn in Jack County through Young and Stephens counties to the border of the Cretaceous in Eastland County. Inliers belonging to the Thrifty appear in the midst of the Cretaceous near Romney and Bethel, and it has been traced south of the sand to the border of the Llano Mountains southwest of Brady. In the northern Pennsylvanian area its thickness is about 150 to 200 feet, in the southern, 100 to 125 feet. The formation has not been subdivided into named members, but three of the limestone beds which have been separately mapped for long distances have been differentiated. The Breckenridge limestone, 3 to 5 feet thick, occurs at the top, the Black Ranch limestone, about the same in thickness, is found 20 to 40 feet below the top, and the Ivan limestone, 50 to 80 feet below the top. The two lower beds have not definitely been identified in the Colorado Valley, though they are possibly equivalent to Drake's "Lower Chaffin" and "Speck Mountain" limestones.

The Harpersville formation is named from a small town 10 miles south of Breckenridge in Stephens County. It includes the strata from the top of the Breckenridge limestone to the top of the Saddle Creek limestone of Drake, and is chiefly characterized by its content of one of the important workable coals in the north Texas Pennsylvanian, "Coal No. 6" of Texas reports. The shales which are the chief constituent rock are carbonaceous and ferruginous, containing siderite and limonite concretions, and locally abundant, well-preserved fossils. The only important limestone in the south is the Saddle Creek member, which consists of two or three beds 1 to 3 feet in thickness separated by shale; but in the north a second limestone, named the Belknap, 30 to 50 feet below the top of the formation, is traceable for a long distance; and in the vicinity of Crystal Falls, Stephens County, a third bed, the Crystal Falls limestone, occurs 60 to 80 feet lower. The total thickness of the Harpersville formation is 200 to 275 feet. The fauna is a fairly large one, but it is very unlike that of the lower portion of the Cisco described in the Graham. The species most common there are here missing, and new species, as *Enteletes hemiplicata*, *Chonetes granulifer meekianus*, *Derbya cymbula*, and other forms, appear. Also species which are present in the lower rocks as a rather unimportant faunal element are here very abundant. The fauna of the Harpersville is indicative of a late portion of the Pennsylvanian. It is approximately equivalent to the Douglas or Shawnee formations of the Kansas section.

The fourth formation of the Cisco, the Pueblo, is named from a town on the Missouri, Kansas & Texas Railway in northeastern Callahan County, where the rocks of this division are typically exposed. It lies conformably upon the Harpersville formation and includes the strata to the top of the persistent Camp Colorado limestone which forms a readily traceable escarpment both in the Colorado and Brazos valleys. The thickness of the formation, which averages from 150 to 200 feet, is largely made up of gray, buff, or reddish shale. The limestone beds at the top are thin, 3 to 6 feet, but are remarkably uniform and persistent. The fauna of the Pueblo is similar to that of the subjacent Harpersville and is typical of the uppermost Pennsylvanian.

The strata above the Pueblo belong to the Moran formation which is defined to include the shale and limestone to the top of the persistent yellow limestones which outcrop typically in the vicinity of Moran, Shackleford County, and in the Moran oil field. These limestones, commonly three in number, are closely associated and are grouped together as the Sedwick member. The Sedwick beds are distinguished by widely distributed and abundant small silicified fossil casts, mainly gastropods. The Sedwick may be identified with little difficulty by reason of this peculiarity of the contained fossils, the lithologic character of the limestones, and the stratigraphic position. The average thickness of the formation is 150 feet in the south and 200 feet or more in the north.

The uppermost division of the Cisco group is named the Putnam formation, from a town in Callahan County. It includes the shale and limestone overlying conformably the Moran formation to the top of the Coleman Junction limestone of Drake which comprises the upper member of the formation. The shale which follows the Coleman Junction bed contains fossils which appear to belong to the Lower Permian, but those which have been found in the limestone are not dissimilar from those in the subjacent divisions of the Cisco. As in Kansas, there appears to be here a gradual transition from the Pennsylvanian to the Permian, and a line of division is more or less arbitrary. The Coleman Junction limestone has been selected as a conspicuous, readily traceable line of such division, but it is possible that future detailed investigations will show the presence of Permian species below this horizon. The thickness of the Putnam formation is 125 to 150 feet in the Colorado Valley, and about 175 feet in the Brazos Valley.

The middle and upper portions of the Cisco, that is, the Thrifty formation and succeeding divisions, correspond in stratigraphic position and faunal character with the upper part of the Kansas section included in the Lansing to Wabaunsee formations. The Texas divisions cannot be correlated precisely on the basis of information at hand with the Kansas formations, but there can be no doubt as to their essential equivalence.

PHYSICAL HISTORY OF THE TEXAS PENNSYLVANIAN

Sedimentation began in the north Texas area in Pottsville time, the sea first advancing into the region probably in the very early Pottsville. Black shale and later a thick mass of limestone were widely deposited about and over the Llano region and northward probably beyond the Red River. The sea of this time was evidently an invasion from the southwest, and the faunas represent the earliest typical marine Pennsylvanian of the continent. The epoch closed with more deposition of carbonaceous muds.

At the end of Bend time the sea withdrew temporarily from the Llano region and probably from most of the north Texas area. However, there was little erosion of the soft Smithwick shale, and the unconformity which is observed at the base of the Strawn is defined mainly by the difference in strike of the younger beds, the conglomerates and very remarkable change in the character of the sediments, and the overlap of the Strawn upon the Bend. The ancient land to the east representing the northeast part of Columbia, or, as it has been termed recently, Llanoria,[1] was notably uplifted and furnished a very great amount of clastic dêbris to the shallow sea lying to the west. This was spread out in irregular lenses with a general delta structure, dipping westward and younger deposits overlapping the older. Coal was deposited locally. The fauna had undergone a marked change from that of Bend time and at least in the upper part of the Strawn was very closely related to the southern Oklahoma Wewoka fauna. This portion, and perhaps all of the Strawn, is referable to Allegheny time.

[1] H. D. Miser, paper presented before the Geological Society of America, December, 1920.

Clearer waters, in which calcareous muds and limestones were the chief accumulating sediments, succeeded, the Canyon group representing the second epoch of dominant limestone formation in the Texas Pennsylvanian. Some 700 or 800 feet of limestones and shales were deposited during this relatively quiet interval, the invertebrate faunas showing only changes which might be anticipated with undisturbed, clear waters. It is probable that the change to dominant limestone deposition in Texas was approximately synchronous with the similar change in the northern part of the mid-continent region above the Cherokee shale.

The beginning of Cisco time is marked by a change in the character of the sediments, a great amount of mud, sand, and gravel being swept from the north and northeast, where the orogenic movement which resulted in the formation of the Arbuckle Mountains and probably an uplift of the ancient land of Llanoria furnished an abundance of materials. The thick, relatively soft, clastic formations which compose the Lower Pennsylvanian in the Arbuckle region would first be exposed to erosion and probably furnished a large proportion of the sediment in the Graham formation of north Texas. When the Lower Paleozoic limestones of the mountain areas were exposed, limestone conglomerates were formed locally (Franks) which were strewn across the eroded edges of the earlier Pennsylvanian. Although there is an important unconformity in this part of the Pennsylvanian of southern Oklahoma, the seas do not appear to have receded more than temporarily from north Texas, for the unconformity at the top of the Graham formation is not a large one. However, the faunas underwent a striking change and throughout the remainder of the Cisco have a very evident late Pennsylvanian aspect. The middle and upper Cisco represents a continuation of mud and sand deposition with an occasional limestone bed and one or two important intervals when coal was formed. There does not appear to have been any marked change with the transition to Permian time in part of the north Texas region, but to the northwest the presence of continental Red Beds sediments characteristic of the Permian appears. In these are found the well-known reptiles and amphibians which lived on the early Permian lands and along the old shores in the north Texas region.